Watch out! Trick question:

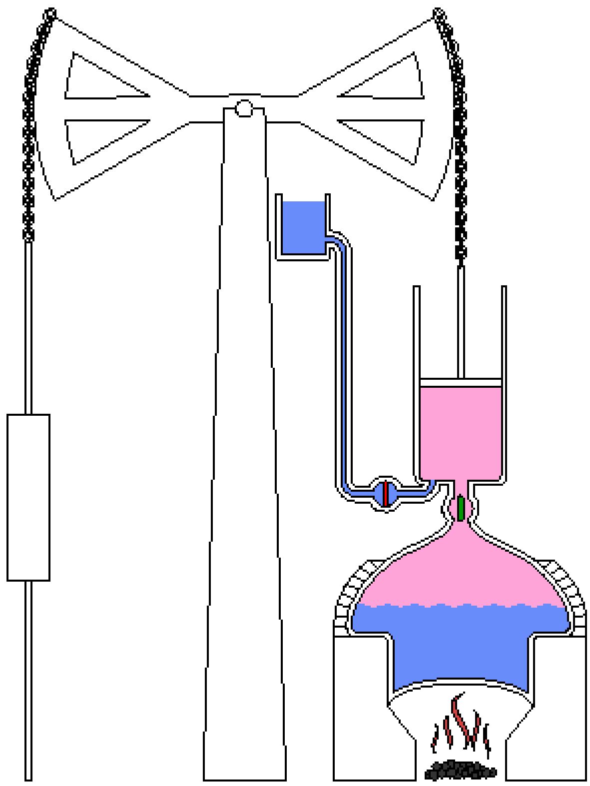
Who invented the steam engine?

Give up?

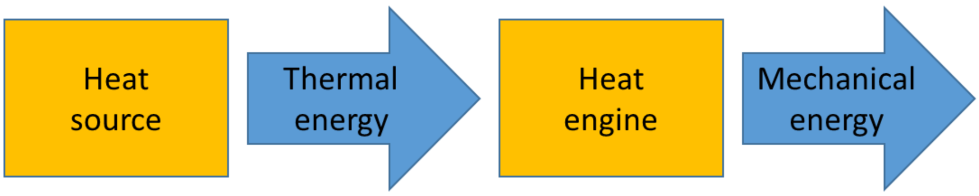
They **all** made major contributions. Such is the nature of technological development – each inventor stands on the shoulders of the giants that have preceded them.

The history of human development is closely linked to the **cost** of energy. Prehistoric hunter-gatherers needed a large land area per person to survive. A much larger population of humans was possible with the invention of agriculture, and then by replacing human mechanical energy with that of animals. But at the end of the middle ages, Europe was faced with the ecological catastrophe of deforestation. People started to obtain thermal energy from coal, but the reserves available close to the surface were soon used up.

In 1712, Thomas Newcomen combined the ideas of Denis Papin and Thomas Savery to invent the first commercial steam engine for pumping water out of mines, allowing deeper mining operations.



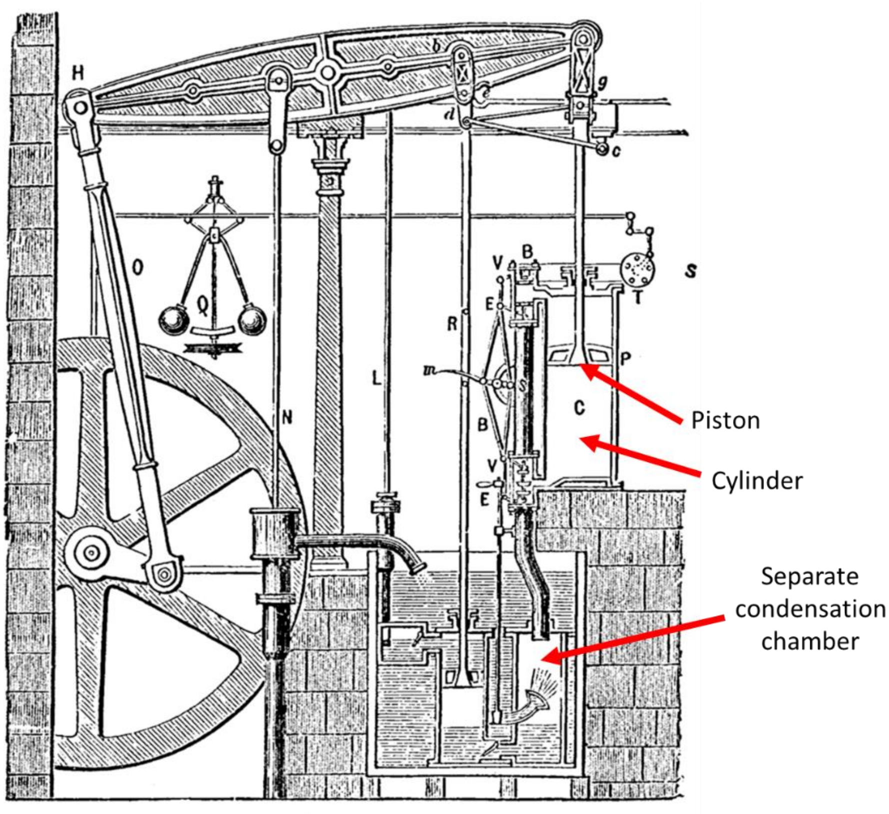
With this heat engine, humans were finally able to convert thermal energy into mechanical energy, marking the start of the industrial revolution.



The cost of energy from a heat engine is made up of

- The capital cost of the machine
- The cost of the fuel for the heat source
- Operating costs

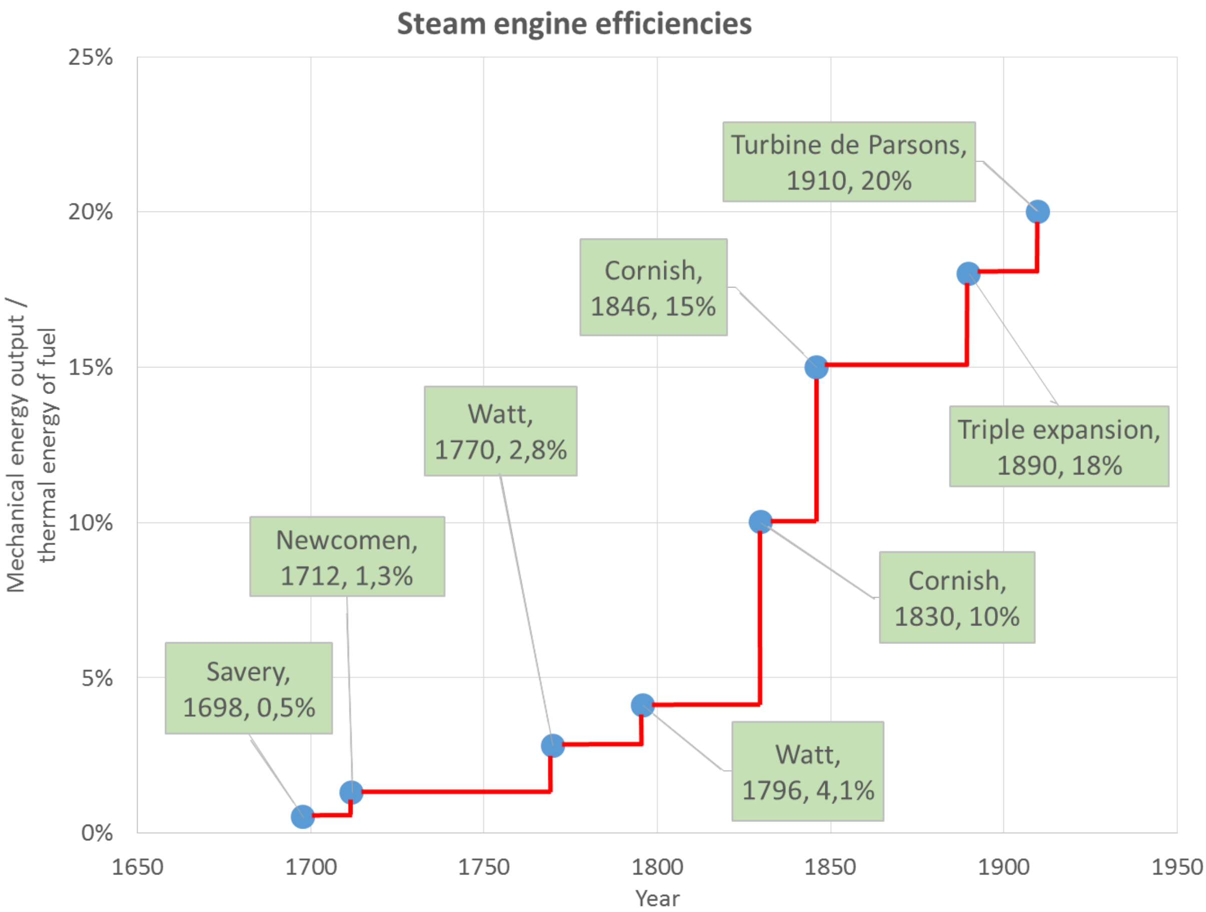
Newcomen’s engine could convert only 1.3% of the coal’s energy into mechanical energy. With such poor efficiency fuel costs were extortionate, but it took another **58 years** until the invention of James Watt to improve things.



Watt’s genius was to realise that the Newcomen engine wasted almost three quarters of the energy in the steam through heating the piston and cylinder. With a separate condensation chamber, efficiency was more than doubled. As the cost of the machine was similar, the energy produced was much cheaper.

Watt partnered with Matthew Boulton, and their company “Boulton & Watt” derived most of their profits from charging a licence fee to the engine owners, based on the cost of the fuel they saved.

Had you thought that James Watt invented the steam engine?



(Source: "Dynamics of Technological Change", L.A. Girifalco, p.484)

The history of the industrial revolution is a race for ever greater heat engine efficiencies. It's true that Watt made a major contribution, but the democratisation of the cost of energy which makes modern life possible was the work of many inventors and engineers.

Newcomen's engine, used only in mining, was rapidly replaced by Watt's. With energy costs reducing thanks to continuous improvement at Boulton & Watt, their machine soon also replaced wind energy from windmills and hydraulic energy from water-wheels, becoming more and more useful.

It is remarkable in the graph above to note that it took 200 years to go from an efficiency of 1.3% to the 20% efficiency of Charles Parsons' first steam turbine. We should never underestimate the difficulty of technological change – often the technologies needed to manufacture a profitable machine progress slower than the theories and ideas of inventors.

Today's combined cycle gas turbine power plants attain efficiencies of over 61%, but in recent times steam engines have been improved in a different way, by changing the heat source.

A large steam engine currently under construction at Flamanville

Uranium and thorium nuclear fuels have an energy density around 1 million times greater than fossil fuels, but the machines required to extract this energy are much more complicated than steam engine boilers. Nuclear energy has very different economics, with minimal fuel costs and the majority of cost coming from the capital invested in the machine.

In 2016 humanity is facing a global warming crisis. Renewable and nuclear low carbon energies are making progress, but energy from fossil fuels is progressing faster **because it is cheaper**. The history of the steam engine shows us that human prosperity improves when the cost of energy reduces. The greatest challenge of the 21st century is to provide each human with a decent level of prosperity and to simultaneously stop global warming and reduce the impact of humans on the environment. The COP21 conference failed to establish a carbon tax because making dirty energy more expensive is politically impossible. Clean energy is an engineering problem – it must be **cheaper than coal**.

The commercial development of nuclear fission is at a point which shares remarkable similarities with that of the steam engine 250 years ago.

- Following initial experiments, only one principle has been commercially deployed
- This technology has reached its limits
- The technology has been on the market for over 50 years
- Fuel use is low
- The cost of energy produced is not very competitive with the alternatives on the market
- A few hundred machines have been produced
- The machines have only one commercial use
- Human civilisation is facing an environmental crisis
- The rate of deployment of the machines is insufficient to solve the environmental crisis
- The theoretical potential remains enormous
- An improved system has been invented, with the potential for a disruptive reduction in the cost of energy
- This new system is in development
- The existing industry is saying that the new system is not feasible [1]

Just like Boulton & Watt, today’s nuclear innovators have realised the critical importance of reducing the cost of fission energy. But instead of trying to reduce fuel consumption, the economics of nuclear power require a reduction in the cost of the machine.

So why are current nuclear energy systems expensive?

When we split the atom, two new atoms are produced which are called fission products. They are highly radioactive and hazardous for humans. These atoms decay at differing rates until they become stable isotopes which are no longer hazardous.

In today’s pressurised water reactors, the fuel is a solid. The fission products remain trapped in the solid material but can escape if the fuel heats up and melts. Because some of the fission products are gases, containment of the reactor is required to avoid their dispersion in the atmosphere in the case of an accident. This containment is complicated and expensive because the system runs at very high pressure. These inherent fragilities require the use of many complicated and expensive safety systems to guarantee an acceptable level of safety.

The capital cost of a nuclear energy system is a function of the inherent safety profile of the reactor system.

In a molten salt reactor the fuel is a liquid. The mixture of salts is designed to remain liquid over a wide temperature range, and to allow the fissile material and most of the fission products to be dissolved in the form of salts which are chemically very stable. Expansion of the liquid according to its temperature ensures a strong inbuilt negative feedback mechanism which gives dynamically stable operation, at atmospheric pressure. With intrinsic safety assured by the physical and chemical design, “liquid fission” enables a much simpler and cheaper reactor.

An international race has begun to bring this technology to market. The magic of entrepreneurship, where a technical architect with an idea meets an investor with funding, is at work to build these machines, with millions of dollars already in play. The disruptive innovation of liquid fission is no longer a question of “if” – it is a question of “who” and “when”.

So who will be the Bolton & Watt of the 21st century?

Nuclear energy will follow the same development curve as the steam engine, but with a difference of about 250 years. Once it has competitive cost and a large production capacity, it will make an active contribution to the fight against global warming.

For liquid fission systems currently under development, the main elements which create value and allow cost to be reduced are:

- The intrinsic safety of the chemically stable liquid fuel
- Elegant, simplified design and well thought out architecture of the whole reactor system
- A higher operating temperature
- A modular approach to building construction, component manufacture, assembly and commissioning

For the future, there remains much potential for further cost reduction, with:

- Breeder reactor systems
- Smaller heat engines which better exploit the high operating temperatures
- A fuel cycle based on thorium, or which incinerates waste from existing reactors
- Material improvements to prolong the life of certain components
- A streamlined process for obtaining operating licenses

…not to mention inventions yet to come.

And like the steam engine, cheaper and smaller nuclear energy systems will find many new applications:

- Supply of industrial process heat
- Production of synthetic liquid fuels using water and carbon dioxide
- Desalination of sea water
- Production of electricity for off-grid communities
- Marine propulsion
- Etc.

This future is possible. It is even probable because it is necessary. With Boulton & Watt's spirit of entrepreneurship we can build cheaper modern steam engines which will bring progress to humanity and to the planet.

[1] When John Smeaton saw the first Watt engine he reported to the Society of Engineers that "Neither the tools nor the workmen existed who could manufacture such a complex machine with sufficient precision".